Puget Sound and the Straits Dissolved Oxygen Assessment

Impacts of Current and Future Human Nitrogen Sources and Climate Change through 2070

DEPARTMENT OF
ECOLOGY
State of Washington

March 2014

Publication No. 14-03-007

Publication and Contact Information

This report is available on the Department of Ecology's website at
https://fortress.wa.gov/ecy/publications/SummaryPages/1403007.html

The Activity Tracker Code for this study is 09-503.

For more information contact:

Publications Coordinator
Environmental Assessment Program
P.O. Box 47600, Olympia, WA 98504-7600
Phone: (360) 407-6764

Washington State Department of Ecology - www.ecy.wa.gov

- Headquarters, Olympia (360) 407-6000
- Northwest Regional Office, Bellevue (425) 649-7000
- Southwest Regional Office, Olympia (360) 407-6300
- Central Regional Office, Yakima (509) 575-2490
- Eastern Regional Office, Spokane (509) 329-3400

Cover graphic by Teizeen Mohamedali:
Marine waters of the Salish Sea (Strait of Georgia, Strait of Juan de Fuca, and Puget Sound).

Puget Sound and the Straits Dissolved Oxygen Assessment

Impacts of Current and Future Nitrogen Sources and Climate Change through 2070

by

Mindy Roberts, Teizeen Mohamedali, and Brandon Sackmann
Environmental Assessment Program
Washington State Department of Ecology
Olympia, Washington 98504-7710

and

Tarang Khangaonkar and Wen Long
Pacific Northwest National Laboratory
Richland, Washington 99352

Water Resource Inventory Area (WRIA) and 8-digit Hydrologic Unit Code (HUC) numbers for the study area

WRIAs

- 1 through 19

HUC numbers

- 17110001 through 17110021

This page is purposely left blank

Table of Contents

List of Figures

List of Tables

Abstract

Pacific Northwest National Laboratory and the Washington State Department of Ecology developed and applied a three-dimensional circulation and dissolved oxygen (DO) model of the Salish Sea (Puget Sound, the Strait of Juan de Fuca, and the Strait of Georgia) to evaluate DO impacts of human nutrient loads, Pacific Ocean conditions, and climate change. Previous reports documented the calibration results. This report summarizes current (2006) and future (for 2020, 2040, and 2070) predicted impacts on DO.

Human nitrogen contributions from the U.S. and Canada to the Salish Sea have the greatest impacts on DO in portions of South and Central Puget Sound. Marine point sources cause greater decreases in DO than watershed inflows now and into the future. Both loads will increase as a result of future population growth and land use change. Most of the Salish Sea reflects a relatively low impact from human sources of nitrogen. However, future human nutrient contributions could worsen DO declines in regions of Puget Sound.

The Pacific Ocean strongly influences DO concentrations under both current and future conditions. If 50-year declining trends in North Pacific Ocean DO concentrations continue, Salish Sea DO would decline far more than from human nutrient loads. However, future ocean conditions are highly uncertain.

Climate change will alter the timing of freshwater flow reaching the Salish Sea. This could worsen impacts in some regions but lessen others. Future air temperature increases would further decrease DO, particularly in shallow inlets.

This is the first assessment of how Salish Sea DO concentrations respond to population increases, ocean conditions, and climate change. Additional analyses are needed to link sediment-water interactions and increase scientific certainty.

Acknowledgements

The authors of this report wish to thank the following people for their contributions to this study:

- Ben Cope (EPA Region 10) provided guidance on the technical approach as well as review and interpretation of the results as part of the project team and as EPA's technical liaison for the National Estuary Program grant.
- Alan Hamlet (University of Notre Dame, formerly with the University of Washington Climate Impacts Group), provided climate model results for future river flow conditions in the Puget Sound region.
- Theogene Mbabaliye and Jessica Saffell (EPA Region 10) managed the National Estuary Program grant.
- The Department of Fisheries and Oceans provided quarterly monitoring data from the Strait of Juan de Fuca and Georgia Straits monitoring stations.
- The project advisory committee met at key points in project development and offered review:
  - George Boggs – Whatcom Conservation District
  - David Brookings – Snohomish County
  - Betsy Cooper – King County
  - Bill Dewey – Taylor Shellfish Co.
  - Tom Eaton – EPA Region 10
  - Lincoln Loehr – Stoel Rives
  - Parker MacCready – University of Washington
  - Paul McElhany – NOAA Northwest Fisheries Science Center
  - Bruce Nairn – King County
  - Jan Newton – PSP Science Panel
  - Tony Paulson – U.S. Geological Survey
  - Scott Redman – Puget Sound Partnership
  - Lynn Schneider – Washington State Department of Health
  - Eugene Sugita – West Point Treatment Plant
  - John Thomas – Washington On-Site Sewage Association
  - Heather Trim – Futurewise (formerly People for Puget Sound)
  - Robert Waddle – Kimberly-Clark (Everett)
  - Phil Williams – City of Edmonds
  - Jeff Wright – City of Everett WPCF

- Betsy Cooper (King County) provided current and future sewered population for the three King County wastewater treatment plants.
- Comments on the external review draft report were provided by Bruce Nairn, Patrick Roe, Shirley Marroquin, Lincoln Loehr, and Parker MacCready.
- Washington State Department of Ecology staff:
    - Josh Baldi, Bob Cusimano, Rob Duff, Karol Erickson, Kevin Fitzpatrick, Melissa Gildersleeve, Will Kendra, Andrew Kolosseus, Kelly Susewind, Sally Toteff, Mark Henley, and Greg Zentner provided review of initial findings.
    - Several Department of Ecology and EPA Region 10 permit writers provided assistance in locating future population served by WWTPs, including Mike Dawda, David Dougherty, Laura Fricke, Mark Henderson, Tonya Lane, and Shawn McKone.

This project has been funded wholly or in part by the United States Environmental Protection Agency under assistance agreement PC-00J279-01 to Department of Ecology. The contents of this document do not necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

This page is purposely left blank

Introduction

Pacific Northwest National Laboratory (PNNL) developed a three-dimensional circulation and dissolved oxygen (DO) model of Puget Sound and the Salish Sea under the direction of the Washington State Department of Ecology (Ecology). The project team also included the Environmental Protection Agency Region 10 and the University of Washington Climate Impacts Group. An advisory committee of regional experts provided review of interim findings.

The model was developed to investigate whether human sources of nitrogen are contributing to low levels of DO measured in parts of Puget Sound. The investigation focused not only on current impacts but also potential future impacts due to population growth and climate change. Figure 1 presents the study area.

Low DO levels can result from natural factors, but human contributions can worsen conditions. Phytoplankton, or algae, grows in the presence of nutrients and sunlight. Excess nutrients, primarily nitrogen, can fuel algae blooms. Decomposition of dead algae and other organic matter draws down oxygen concentrations near the bottom, where the atmosphere cannot replenish oxygen. This document describes the application of the calibrated model to quantify the relative influences of human nutrient contributions, Pacific Ocean conditions, and climate change on DO in Puget Sound and the Straits.

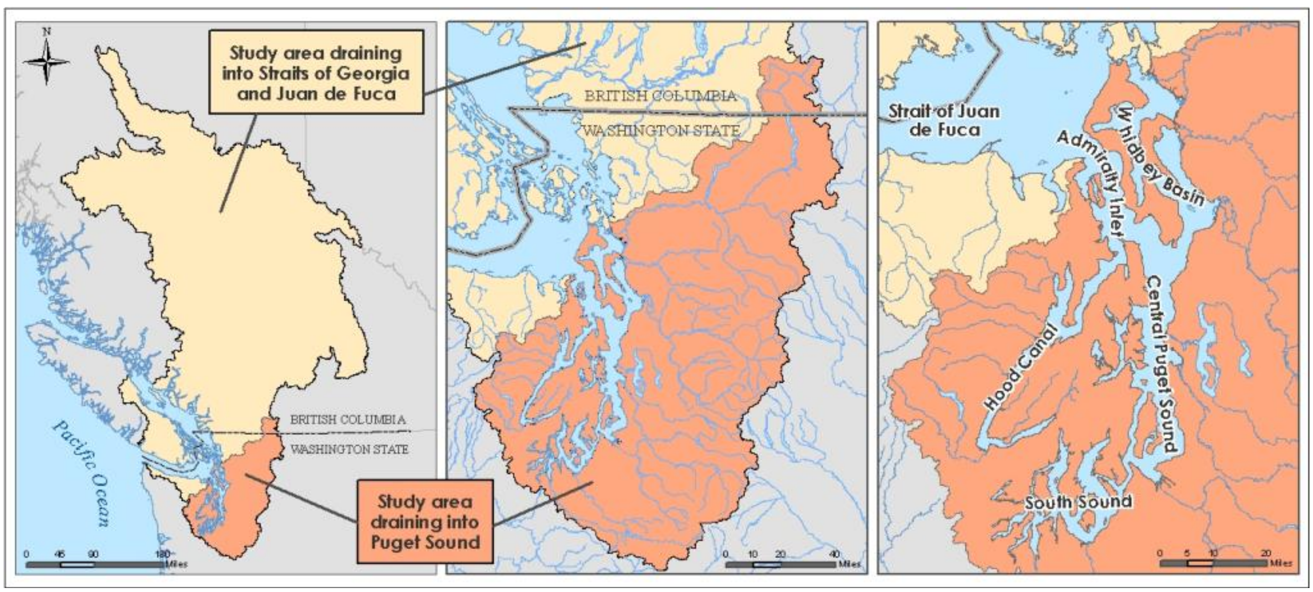

Figure 1. Puget Sound and the Straits of the Salish Sea with land areas discharging to marine waters evaluated in this study.

Pacific Ocean Conditions

Pacific Ocean water enters the Salish Sea primarily through the Strait of Juan de Fuca, with a lesser exchange through Johnstone Strait and around the north end of Vancouver Island in Canada. The marine water that enters the Salish Sea reflects conditions in the northeast Pacific Ocean that are influenced by complex circulation and water quality processes.

Water that upwells off the coast of Washington and enters the Strait of Juan de Fuca was last in contact with the atmosphere in the western Pacific Ocean. The North Pacific Current carries subarctic water eastward across the Pacific Ocean from the coast of Japan and Russia where it splits into north and south currents. The Alaska Current carries water northward to the Alaska gyre in the Gulf of Alaska. The California Current travels southward along the continental shelf of the west coast. The California Undercurrent carries subtropical waters northward from the Pacific equatorial region to Washington. Pacific equatorial subtropical waters are warmer, have higher salinity and nutrients, and have lower oxygen than subarctic waters. Both water masses influence the Strait of Juan de Fuca (Thomson and Krassovski, 2010).

Mesoscale eddies, which are large circulating currents hundreds of miles in diameter, transport water near the Strait of Juan de Fuca as well. Coastal processes along the west coast of North America, such as increased primary productivity (Sackmann et al., 2004) and the Columbia River plume (Banas et al., 2009) also influence water near the Strait. Finally, the direction and magnitude of coastal winds affects the strength of upwelling.

Small changes in these phenomena affect the water properties that enter the Strait of Juan de Fuca. Water in the Alaska gyre is cool and fresh, while water from the California Undercurrent is warm and saline. Mesoscale eddies are associated with warm freshwater. Climate cycles, such as the Pacific Decadal Oscillation (PDO) and El Nino-Southern Oscillation, have been linked to changes in large-scale meteorology and terrestrial hydrology (Mote et al. 2003; Hamlet and Lettenmaier 1999b, 2007). Climate cycles also influence circulation patterns and temperatures in the northeast Pacific (Whitney et al., 2007). All potentially influence stratification, which affects deep-water DO concentrations due to enhanced or restricted vertical mixing. Changes in these processes affect the incoming water through the Strait of Juan de Fuca.

Oxygen concentrations, which reflect complex interactions of physical, chemical, and biological processes, have declined in the North Pacific over a 50-year period in water masses representing a mix of subarctic and subtropical characteristics (Whitney et al., 2007; Pierce et al., 2012). Climate cycles and circulation patterns explain some of the variability in the long-term records. However, the rate of decline has increased recently compared with the 50-year trend, and researchers are unclear if this is part of a longer-term cycle or an acceleration of a downward trend.

Climate change could further decrease oxygen levels in waters that enter the Strait of Juan de Fuca. Freshening of the surface waters and increased heat flux due to climate change could reduce vertical mixing of oxygen to deeper waters by increasing stratification in the upper layer of the ocean (Whitney et al., 2007). Higher alongshore winds from north to south near the coast could also increase upwelling and pull more water from depths of 100 to 250 meters (Whitney et al., 2007). The Pacific Ocean is the dominant source of both water and nitrogen to Puget Sound and the Straits (Mackas and Harrison, 1997). Small changes in nitrogen concentrations entering the Salish Sea could produce large loads to Puget Sound and the Straits.

Contributions from Watershed Inflows and Marine Point Sources

The Salish Sea watershed delivers freshwater through rivers, streams, stormwater infrastructure, and overland flow from shoreline areas as well as from wastewater treatment plant effluent. This freshwater mixes with Pacific Ocean water. The Fraser River is the largest single source of freshwater to the Salish Sea and drains most of the province of British Columbia in Canada. Most of the freshwater reaching the Strait of Georgia comes from British Columbia, but the Nooksack and Samish Rivers, along with many smaller streams, drain to the Strait of Georgia from U.S. watersheds. Similarly, the Strait of Juan de Fuca receives freshwater inputs from the southwest coast of Canada's Vancouver Island as well as from U.S. rivers draining the north side of the Olympic Peninsula.

Within Puget Sound, defined as the area south of Admiralty Inlet, watersheds deliver different amounts of freshwater to marine waters and the amount varies over the year. Whidbey Basin receives water from the Skagit River, the largest freshwater source to Puget Sound**,** as well as the Stillaguamish and Snohomish Rivers. Hood Canal receives water flowing off the eastern slope of the Olympic Mountains and the western Kitsap Peninsula, and Central Puget Sound receives watershed inflows from the Cedar, Green, and Puyallup River watersheds and portions of the Puget Lowland to the east and west. The two largest rivers draining to South Puget Sound are the Nisqually and Deschutes, but South Puget Sound also receives freshwater from portions of the Puget Lowland.

Watershed inflows entering Puget Sound and the Straits deliver loads of nitrogen. Nitrogen naturally occurs in rivers and streams entering marine waters. However, human activities have increased nitrogen loads above naturally occurring levels. As detailed in Mohamedali et al. (2011), the relative load contributions vary among watersheds. While the Fraser River delivers the largest single freshwater nitrogen load to the Salish Sea, the load per unit watershed area is the lowest in the study area (Figure 2). Smaller watersheds such as the Nooksack River and the Deschutes River have significantly higher unit-area loads of nitrogen.

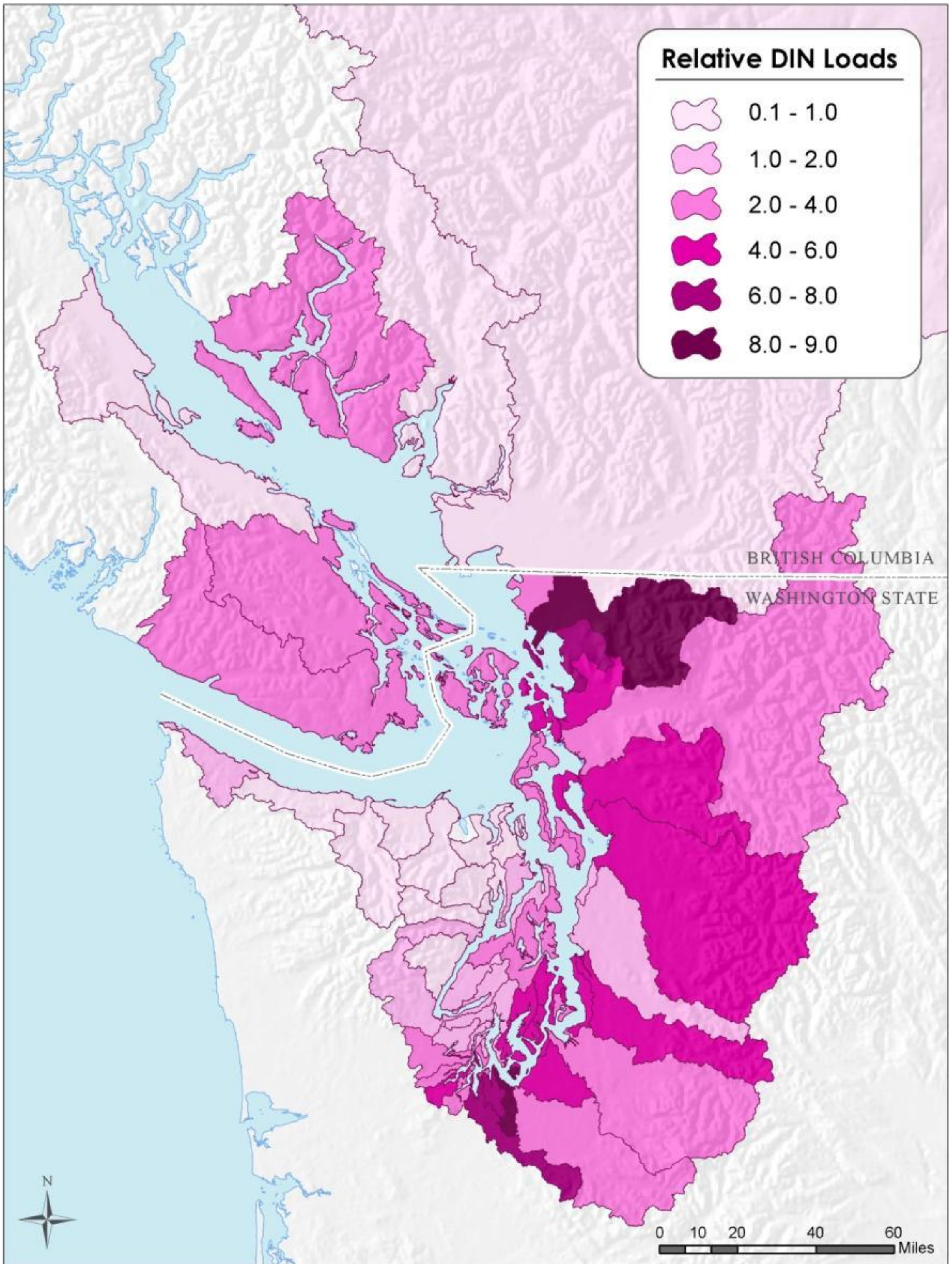

Figure 2. Annual relative dissolved inorganic nitrogen (DIN) loads from watersheds (individual watershed unit-area load compared with entire study area) for the period 1999-2008.

Source: Mohamedali et al. (2011).

Watershed nitrogen concentrations and loads reflect the combination of natural and human contributions. Natural nitrogen concentrations in rivers are governed by nitrogen concentrations in rainfall and processes within a forested watershed. This baseline condition can change if regional air emissions alter the rainfall nitrogen concentration or forest is converted to other developed land uses. In the watersheds, human contributions include point source discharges, such as wastewater treatment plants. Nonpoint sources from lands not covered by native forests also increase human contributions above natural levels. Not all nitrogen generated in a watershed reaches Puget Sound and the Straits. The amount of nitrogen delivered varies seasonally due to changes in flow rates, sources of nitrogen, and attenuation through processes such as plant uptake and denitrification.

The marine waters of the Salish Sea also receive direct discharge of treated effluent from wastewater treatment plants. These include plants serving greater Vancouver and Victoria as well as other communities in Canada. In the US, 78 municipal wastewater treatment plants and 10 industrial facilities discharge treated effluent through outfalls to Puget Sound and the Straits. While the volume of water is small relative to watershed inflows, municipal WWTP effluent contains higher concentrations of nitrogen. Industrial plants generally have lower concentrations of nitrogen than municipal plants but are included for completeness. Municipal marine point source nitrogen loads increase from current loads with increasing population served by the plants. Figures 3 and 4 summarize loads of dissolved inorganic nitrogen discharged to the Salish Sea as described in Mohamedali et al. (2011).

Population will continue to increase in the watershed draining to Puget Sound and the Straits. In addition, the proportion of the watershed covered by developed (non-forested) lands will also continue to increase. If no changes to current management actions occur, this increase in population and developed lands will result in increased nitrogen loads delivered to marine waters. A fundamental question is how much higher population and increased development could decrease marine water DO concentrations. Climate change could also alter the amount and timing of nitrogen loads reaching Puget Sound and the Straits, primarily through changes in hydrology.

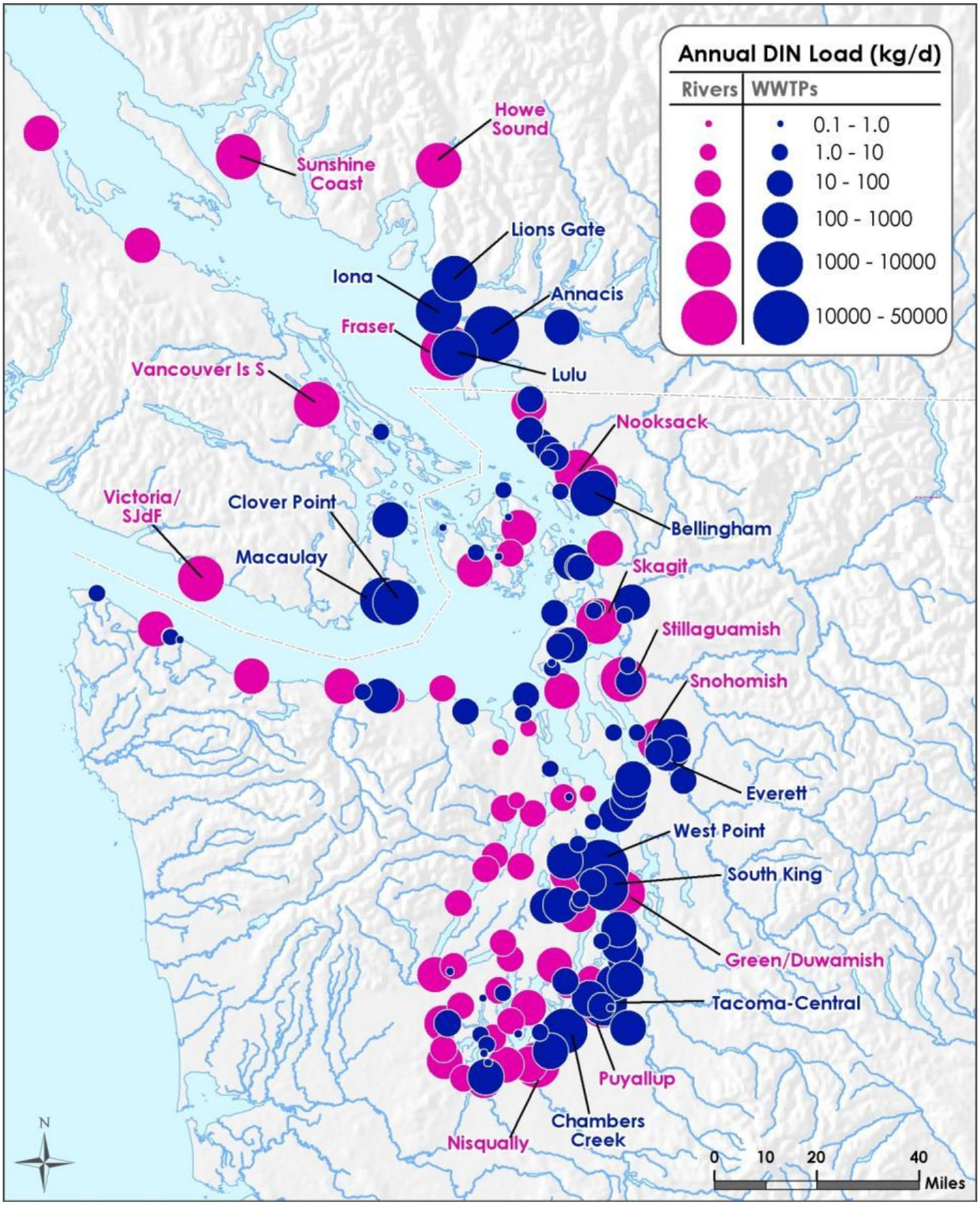

Figure 3. Mean annual dissolved inorganic nitrogen (DIN) loads from watershed inflows (rivers) and marine point sources (WWTPs) for 1999 to 2008.

Source: Mohamedali et al. (2011).

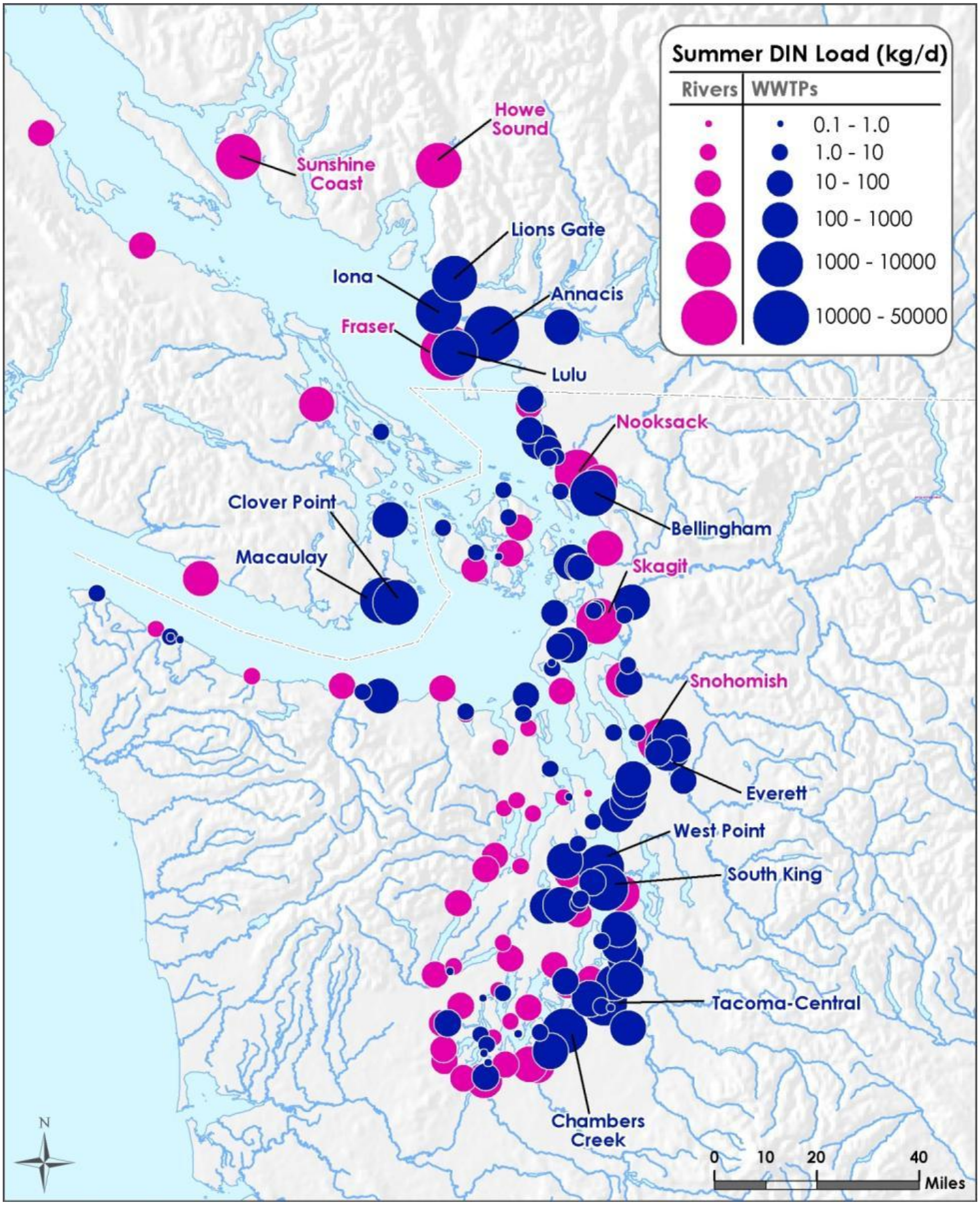

Figure 4. Summer dissolved inorganic nitrogen (DIN) loads from watershed inflows (rivers) and marine point sources (WWTPs) for 1999 to 2008.

Source: Mohamedali et al. (2011).